

## PERISTALTIC PUMP

### FIELD OF THE INVENTION

This invention relates to devices for controlling fluid flow.

### BACKGROUND OF THE INVENTION

Peristaltic pumps are used for controlling the flow of a fluid in an elastic  
5 tubular conduit. These pumps have many medical and industrial applications.

In one form of peristaltic pumps, a rotor is used to rotate a plurality of  
eccentric cams. Each cam, in turn, intermittently collapses the elastic conduit at an  
initial contact point, and slides along the conduit over a short distance as the rotor  
turns. A second cam contacts the initial contact point and the first cam is then  
10 released from the conduit as the second cam slides along the conduit. As this  
process is repeated, a flow of fluid in the conduit is generated in the direction of the  
sliding of the cams.

U.S. Patent No. 5,996,964 to Ben-Shalom discloses a peristaltic pump in  
which a plurality of electromagnets are arranged along an elastic conduit. The  
15 electromagnets are activated according to a temporo-spatial scheme in order to  
generate undulations along a magnetizable membrane that is disposed along the  
conduit. The undulations in the membrane generate undulations in the wall of the  
conduit, which in turn generate a flow of fluid in the conduit.

### SUMMARY OF THE INVENTION

20 The present invention provides a peristaltic pump for generating a flow of  
fluid in a elastic tubular conduit. The pump comprises a plurality of electrically  
operated valves that are arranged along the conduit. Each valve has a valve head  
that alternates between two positions, referred to herein as the "*up position*" and a

- 2 -

"down position". The designations "up", "down", "left" and "right" are used herein only for the sake of clarity in describing the invention, and the invention is not limited to any particular orientation. When a valve head is in its down position, the valve head presses on a segment of the conduit so as to obstruct the lumen of the conduit in the segment, thus preventing fluid from entering the segment. When the valve head is in its up position, the lumen of the conduit in the segment is open, and fluid may flow into the segment.

Electric power from a power supply is distributed among the valves according to a predetermined temporo-spatial pattern by a driver unit. This generates a temporo-spatial array of valve head positions, which in turn generates a flow of fluid in the conduit.

The invention thus provides a pump for generating fluid flow in an elastic tubular conduit having a lumen, comprising:

- (a) a plurality of electrically operated valves, each valve being positionable adjacent to the conduit, each valve having a valve head, the valve head configured to alternate from a first position in which the lumen of the conduit adjacent to the valve head is unobstructed and a second position in which the lumen of the conduit adjacent to the valve head is obstructed;
- (b) a driver configured to control the positions of the valve heads, so as to execute a predetermined temporo-spatial array of valve head positions.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

**Fig. 1** shows a peristaltic pump in accordance with one embodiment of the invention;

- 3 -

**Fig. 2** shows a valve used in the pump of Fig. 1;

**Fig. 3** shows a temporo-spatial array of valve activation for a pump having three valves in accordance with one embodiment of the invention;

**Fig. 4** shows a temporo-spatial array of valve activation for a pump having 4 valves in accordance with another embodiment of the invention;

**Fig. 5** shows a peristaltic pump having 4 valves arranged in two dual valves in accordance with another embodiment of the invention;

**Fig. 6** shows the construction of a dual valve;

**Fig. 7** shows a peristaltic pump in accordance with another embodiment of the invention;

**Fig. 8** shows the pump of Fig. 7 in conjunction with an elastic tubular conduit held in a sleeve;

**Fig. 9** shows a pump in accordance with another embodiment of the invention;

**Fig. 10a** shows a perspective view and **Fig. 10b** shows an exploded view of a driving mechanism for use in a peristaltic pump of the invention;

**Fig. 11** shows stages in the mechanical cycle of the driving mechanism of Fig. 10;

**Fig. 12** shows a pump in accordance with another embodiment of the invention;

**Fig. 13** shows a portable pump of the invention,

**Fig. 14** shows the pump of Fig. 13 after detachment of the control panel;

**Fig. 15** shows an anti-free-flow device; and

**Fig. 16** shows another anti-free-flow device.

## **DETAILED DESCRIPTION OF THE INVENTION**

Fig. 1 shows schematically a peristaltic pump generally referred to as **10** in accordance with one embodiment of the invention. The pump **10** is used to generate a flow of fluid in a tubular conduit **12** having an elastic wall. The tubular conduit **12** may have any cross-sectional shape such as circular, square, rectangular,

- 4 -

and so on. A plurality of electrically operated valves 14 are arranged along the conduit 12. Electric power from a power supply 16 is distributed among the valves according to a predetermined temporo-spatial pattern by a driver unit 18 via cables 20.

5 Fig. 2 shows the structure of the valve 14 in detail. The valve 14 comprises an electromagnet formed from a wire coil 24. A permanent magnet 28 is attached to a valve head 30. When current flows in a first direction in the coil 24, a magnetic field is generated that raises the magnet 28 and head 30 so as to position them proximate to the electromagnet 24 as shown in Fig. 2a. When current flows in the  
10 opposite direction in the coil 24, a magnetic field is generated that lowers the magnet 28 and head 30 so as to position them distal to the electromagnet 24, as shown in Fig. 2b. The coil 24 is enclosed in a cylindrical housing 32. Guide rods 34 maintain the head 30 coaxial with electromagnet 24 as the head travels from the position shown in Fig. 2a (referred to herein as the "*up position*") to the position  
15 shown in Fig. 2b (referred to herein as the "*down position*").

As shown in Fig.2, the head 30 may have a rectangular cross-section when viewed along the longitudinal axis of the coil 24. This is by way of example only, and the head 30 may have any shape as required in any particular application. For a head having a rectangular cross section, one dimension of the rectangular cross-  
20 section (indicated by y in Fig. 2) is selected to be slightly larger than half the circumference of the conduit 12 (i.e. slightly larger than the width of the conduit when flattened).

Referring again to Fig. 1, the valves 14 are oriented adjacent to the conduit 12 with the y dimension perpendicular to the axis of the conduit 12. The other  
25 dimension of the head 30 (indicated by x in Figs. 1 and 2) is parallel to the axis of the conduit 12. As seen in Fig. 1, the x-dimension may be different for different valves. Thus, for example, the x-dimension of valve 14a is greater than the x-

- 5 -

dimension of valve **14b**. The head of the valve **14a**, for example, is shown in its up position. The head of the valve **14d** is shown in its down position.

When a valve head is in its down position, the lumen of the segment adjacent to the valve is obstructed, and fluid cannot flow into the segment. As shown in Fig. 1, the valve head preferably contacts the conduit **12** obliquely, for example by an angle  $\theta$  of about  $4^\circ$ . Due to the elasticity of the conduit, when a valve head is brought from its down position to its up position, the lumen of the segment of the conduit adjacent to the valve becomes unobstructed, and fluid may flow into that segment of the conduit. The elastic conduit **12** is preferably pre-loaded by limiting the elastic expansion of a segment of the conduit when the valve head adjacent to the segment is brought from its down position to its up position, so that some elastic strain is always present in all segments of the conduit adjacent to valve heads. This decreases the variability in the volume flow that occurs when a valve moves from one position to another.

The driver **18** is configured to determine the polarity of a voltage applied to the coil **24** of each valve **14** according to a predetermined temporo-spatial array of voltages, so as to generate the temporo-spatial array of the positions (up or down) of the valve heads **30** that generates a flow of fluid in the conduit **12**.

Fig. 3 shows schematically an example of a temporo-spatial array of valve activation that may be used with the pump of the invention. This is by way of example, and any temporo-spatial array of valve positions that generates a flow of fluid in the conduit **12** may be used with the pump of the invention. The example of Fig. 3 relates to a pump having three valves. This, however, is only to simplify the explanation of the operation of the pump, and, a pump in accordance with the invention may have any number of valves. For simplicity, only the valve heads **40a**, **40b** and **40c** of the valves is shown in Fig. 3.

In the initial configuration **51** of the valve heads, the three valve heads **40a**, **40b** and **40c** are in their down position so that the lumen of the conduit **12** is

- 6 -

obstructed in the segments of the conduit 12 adjacent to the valve heads 40 a, 40b, and 40c. In stroke 52, the valve head 40a is brought to its up position, so that the lumen of the conduit 12 is open under the valve 40a. The pump now has the configuration 53. Stroke 52 causes fluid to flow into the conduit 12 in the portion  
5 of the lumen that was opened by raising valve 40a from its down position to its up position. The flow of fluid is from left to right under the valve head 40a. The volume of fluid that flows is proportional to the x-dimension of the head of the valve 40a. In stroke 54, valve head 40b is raised to its up position, so that the pump acquires the configuration 55. Stroke 54 causes fluid to flow into the segment of  
10 conduit 12 that was opened by raising valve 40b from its down position to its up position. No fluid flows out of the pump during stroke 54. In stroke 56, valve head 40a is lowered. Stroke 56 causes an amount of fluid that is proportional to the x-dimension of the valve head 40a to flow from left to right under the valve head 40b. The pump now has the configuration 57. In stroke 58, valve head 40c is raised  
15 to its up position, so that the pump assumes the configuration 59. Stroke 58 causes an amount of fluid proportional to the x-dimension of the valve head 40c to flow in the negative direction under the valve head 40c.

In stroke 60, valve head 40b is lowered causing an amount of fluid proportional to the x-dimension of the valve head 40b to flow in the positive  
20 direction. The pump thus acquires the configuration 61. In stroke 62, the valve 40c is lowered, causing 1 volume unit to flow in the positive direction. The valve heads 40 are now all in their down position, and the cyclic temporo-array may begin again.

Fig. 4 shows a temporo-spatial array for activating a pump having 4 valves.  
25 For convenience, a valve head in its down position is represented as a 1, and a valve in the up position is represented as a 0. The four valve heads are referred to as  $a_1$ ,  $a_2$ ,  $a_3$ , and  $a_4$ . This array begins with valve heads  $a_1$  and  $a_2$  in their down position, and valve heads  $a_3$  and  $a_4$  in their up position (configuration 500). In the first stroke of the pump (stroke 505), valve head  $a_1$  is raised and valve  $a_3$  is lowered, and the  
30 pump acquires the configuration 510. Valve head  $a_2$  is then raised and valve  $a_4$  is

- 7 -

lowered (stroke 515) so that the pump acquires the configuration 520. Valve head  $a_1$  is then lowered and valve head  $a_3$  is raised (stroke 525) leading to configuration 530. Valve head  $a_2$  is then lowered and valve head  $a_4$  is raised (stroke 535). The configuration of the pump thus returns to configuration 500, and the cycle may  
5 begin again.

Fig. 5 shows a pump 600 in accordance with another embodiment of the invention that executes the temporo-spatial array of valve activation shown in Fig. 4. In this embodiment, a segment of a elastic tubular conduit 605 is fixed to a base 610 by clips 615 so that the segment of the conduit 605 fixed to the base 610  
10 has an "S" shape, as shown in Fig. 5b.

The pump 600 comprises two dual valves 620a and 620b. The dual valve 620a has two valve heads 625a and 625c, and the dual valve 620b has two valve heads 625b and 625d. The dual valves are fixed to the base 610 via a bracket 630 so that the valve heads 625a, 625b, 625c and 625d are located over the points a, b,  
15 c, and d, respectively, along the conduit 605. Each of the valve heads 625 has an up position in which the lumen in the conduit 605 under the valve head is open allowing fluid flow, and a down position in which the lumen under the valve head is obstructed, preventing fluid flow. The design of the dual valve 620a is shown schematically in Fig. 6. The valve heads 625a and 625c are attached to opposite  
20 ends of an iron bar 635. The lever bar is pivotable around an axle 645. When the lever bar is in the configuration shown in Fig. 6a, the valve head 625a is in its up configuration, and the valve head 625c is in its down configuration. When the lever bar is in the configuration shown in Fig. 6b, the valve head 625a is in its down configuration, and the valve head 625c is in its up configuration. Movement of the  
25 lever bar is controlled by an electromagnet 640. A "U" shaped iron bar 642 passes through the interior of a wire coil 647. A pair of permanent magnets 650a and 650b are attached at either end of the lever bar. When current flows in one direction in the coil 647, the lever bar assumes the configuration shown in Fig. 6a. Attraction between the magnet 650a and the bar 642 latches the lever bar in this configuration.  
30 When current flows in the other direction in the coil 647, the lever bar switches to

- 8 -

the configuration shown in Fig. 6b. Attraction between the magnet **650b** to the bar **642** latches the lever bar in this configuration. Operation of the dual valve **620b** is similar to that just described for dual valve **620a**.

Due to the construction of the dual valve **620a**, the valve head **625a** and **625c** are never both open or closed simultaneously. Similarly, the valve heads **625b** and **625d** are never both opened or closed simultaneously. Note that in the temporo-spatial array of valve positions shown in Fig. 4 that is to be executed by embodiment, valve heads **a<sub>1</sub>** and **a<sub>3</sub>** are never open or closed simultaneously. This also applies to valves **a<sub>2</sub>** and **a<sub>4</sub>**.

Fig. 7 shows another embodiment of a pump in accordance with the invention that executes the temporo-spatial array of valve activation shown in Fig.4. In this embodiment, a lever **810a** is rotatable around a pivot **815a**. The lever **810a** has a notch **820a** at a notched end **825a** that is close to the center of the pump **800**. The lever **810a** is pivotable around the pivot **815a** from a first position in which the notch **820a** is lowered as shown in Fig. 7, and a second position in which the notch **820a** is raised (not shown). The position of the lever **810a** is determined by a pair of electromagnets **805a** and **806a**. When the electromagnet **805a** is activated, the lever **810a** assumes its first position in which the notch **820** is lowered. A permanent magnet **840a** latches the lever **810a** in this position. When the electromagnet **806a** is activated, the lever **810a** assumes its second position in which the notch **820** is raised. A permanent magnet **842a** latches the lever **810** in this position.

A second lever **845a** has a first valve head **855a** and a second valve head **856a**. The lever **845a** is rotatable about a pivot **850a** from a first position in which the valve head **855a** is higher than the valve head **856a**, as shown in Fig. 7, and a second position in which the valve head **855a** is lower than the valve head **856a**. The lever **845a** includes an extension **860a** having a terminal projection **865a** that mates with the notch **820a**. The position of the lever **845a** is determined by the position of the lever **810a**. When the lever **810a** is in its first or second position, the lever **845a** is also in its first or second position, respectively.



- 9 -

Another lever **810b** is rotatable around a pivot **815b**. The lever **810b** is pivotable around the pivot **815b** from a first position in which a first end **825b** is raised, as shown in Fig. 7, and a second position in which the first end **825b** is lowered (not shown). The position of the lever **810b** is determined by a pair of  
5 electromagnets **805b** and **806b**. When the electromagnet **806b** is activated, the lever **810b** assumes its first position. A permanent magnet **842b** latches the lever **810b** in this position. When the electromagnet **805b** is activated, the lever **810b** assumes its second position. A permanent magnet **840b** latches the lever **810b** in this position.

10 A lever **845b** has a first valve head **855b** and a second valve head **856b**. The lever **845b** is rotatable about the pivot **815b** from a first position in which the valve head **855b** is higher than the valve head **856b**, as shown in Fig. 7, and a second position in which the valve head **855b** is lower than the valve head **856b**. When the lever **810b** is in its first or second position, the lever **845b** is also in its first or  
15 second position, respectively.

The temporo-spatial array of activation of the four electromagnets **805a**, **806a**, **805b**, and **806b**, is determined by a driver (not shown) so as to activate a predetermined temporo-spatial array of valve head positions. Valve heads **855a**, and **856a** are never open or closed simultaneously. The same also applies to **855b** and  
20 **856b**. This is consistent with the temporo-spatial array of valve head activation shown in Fig. 4.

Fig. 8 shows the pump **800** in conjunction with an elastic tubular conduit **905**. The tubular conduit **905** is held in a sleeve **910**. The sleeve **910** is reversibly attached onto the pump **800** so that when the lever **845a** is in its first position, the  
25 segment of the tubular conduit **905** adjacent to the valve head **855a** is unobstructed while the portion of the tubular conduit **905** adjacent to the valve head **856a** is obstructed. The conduit **905** is adapted at each of its end to mate with extension conduits (not shown), for example, by means of male and female luer fittings at either end. The conduit **905** and the sheath may be provided as a single disposable  
30 unit.

- 10 -

Fig. 9 shows schematically another embodiment of a pump in accordance with another embodiment of the invention. This embodiment, generally indicated by 915, is used for generating fluid flow in an elastic tubular conduit 920 having a section 930 of large cross sectional area (referred to herein as the "expanded section"), flanked by regions 935a and 935 b of small cross section area (referred to  
5 section"), flanked by regions 935a and 935 b of small cross section area (referred to herein as the "narrow sections").

The pump includes one or more valves 925 that are positionable adjacent to the expanded section 930 of the conduit 920. Valves 940a and 940b are positionable adjacent to the narrow section 935a and 935b, respectively. Four valves 925 are  
10 shown in Fig. 9. This is by example only, and any number of valves 925 maybe used as required by any particular application. The valves 925 and the valves 940 may have for example, the structure described above in reference to Fig.2. Each of the valves 925 has a valve head 927, and each of the valves 940 has a valve head 942. The valve heads 927 have an up position in which a portion of the expanded  
15 section 930 adjacent to the valve is not obstructed, and a down position in which a portion of the expanded section 930 adjacent to the valve is at least partially obstructed. The valve heads 927 may have the same stroke length (the distance traveled by the valve head between its up position and its down position), or the valve heads 927 may have different stroke lengths. The valves 925 may be  
20 positioned in any array adjacent to the expanded section 930 (i.e. in a straight line, or in a random array). Due to the large cross sectional area of the expanded region 930, when a valve head 927 is in its down position, flow of the fluid in the expanded region 930 is possible around the valve head.

Electric power from a power supply (not shown) is distributed among the  
25 valves 925 and 940 according to a predetermined temporo-spatial array by a driver unit (not shown).

When a valve head 942a or 942b is in its down position, the segment of the narrow region 935a or 935b, respectively, is obstructed. In use, a valve head 942a or 942b is brought to its down position so as to obstruct the narrow section 935a or  
30 935b, respectively. One or more of the valve heads 927 are then brought to their

- 11 -

down position so as to decrease to volume of the expanded section 930. The valve heads 927 may be brought to their down position, for example, either simultaneously or sequentially. When the valve head 942a is in its down position and the valve head 942b is in its up position, lowering one or more of the valve heads 927 will cause fluid to flow from the expanded section 930 in the narrow section 935b of the conduit 920. Similarly, when the valve head 942b is in its down position and the valve head 942a is in its up position, lowering one or more of the valve heads 927 will cause fluid to flow from the expanded section 930 in the narrow section 935a of the conduit 920. The pump 915 may thus be used to generate a flow from the expanded section 930 to either one of the narrow sections 935.

Fig. 10a shows a perspective view of a driving mechanism 120 that may be used in a pump of the invention. The mechanism 120 is shown in an exploded view in Fig. 10b, and a front view of the mechanism 120 is shown in Figs. 11a to 11g. The mechanism 120 includes an X-shaped metal lever 122 pivotable around an axis 124. A first auxiliary lever 126 and a second auxiliary lever 128 also pivot around the axis 124. An electromagnet 130 is used to generate a magnetic field between a first metal core arm 132a and a second metal core arm 132b.

The lever 122 has four arms 134a, 134b, 134c, and 134d, with arms 134a and c diametrically opposite each other, and arms 134b and d diametrically opposite each other. The first auxiliary lever 126 has first and second arms 126a and b, and the second auxiliary lever 128 has first and second arms 128a and b.

In Fig. 11a, the driving mechanism 120 is shown with the lever 122 in a configuration in which lever arms 134a and c are between the first and second core arms 132a and b, and lever arms 134b and d are outside the core arms 132a and b. The distance between the lever arm 134d and the first arm 128a and the distance between the lever arm 134b and the second arm 128b are both less than the distance between the lever arms 134c and a from the first and second arms 126a and b. When the electromagnet 130 is activated with the lever in the configuration shown in Fig. 11a, the second auxiliary lever 128 rotates counterclockwise in the

- 12 -

direction of the arrows 133, until it contacts the lever arms 134b and d, as shown in Fig. 11b. The second auxiliary lever 128 continues to move counter clockwise in the direction of the arrows 133, urging the lever 122 counterclockwise in the direction of arrows 138 (Figs. 11b and c). Counterclockwise movement of the lever 5 122 and the second auxiliary lever 128 continues until one of the valve heads contacts and obstructs the tubular conduit 905 (see Fig. 8). The mechanism 120 is now in the configuration shown in Fig. 11d.

The electromagnet 130 is then deactivated. A repulsion between the arm 128a and the arm 134d causes the second auxiliary lever 128 to rotate clockwise in 10 the direction of the arrows 144 (Fig. 11d), until the mechanism 120 acquires the configuration shown in Fig. 11e. The repulsion may be due, for example to a first permanent magnet 142 located on the arm 128a and a second permanent magnet 143 located on the arm 134d, as shown in Fig. 11. Alternatively, the repulsion may be due to a spring mechanism (not shown).

15 In the configuration shown in Fig. 11e, the lever arms 134b and d are between the first and second core arms 132a and b, and lever arms 134a and c are outside the core arms 132a and b. The distance between the lever arm 134d and the first arm 128a and the distance between the lever arm 134b and the second arm 128b are both greater than the distance between the lever arms 134c and a from the 20 first and second arms 126a and b. The electromagnet 130 is now reactivated. The first auxiliary lever 126 rotates clockwise in the direction of the arrows 146, until it contacts the lever arms 134a and c, as shown in Fig. 11f. The first auxiliary lever 126 continues to move clockwise in the direction of the arrows 146, urging the lever 122 clockwise in the direction of arrows 150 (Fig. 11f). Clockwise movement 25 of the lever 122 and the first auxiliary lever 126 continues until one of the valve heads contacts and obstructs the tubular conduit 905 (see Fig. 8)..

The electromagnet 130 is then deactivated. A repulsion between the arm 126b and the arm 134a causes the first auxiliary lever 126 to rotate counterclockwise in the direction of the arrows 154 (Fig. 11g), until the mechanism 30 120 acquires the configuration shown in Fig. 11a. This repulsion may be due, for

- 13 -

example, to a third permanent magnet **152** located on the arm **126b** and a fourth permanent magnet **155** located on the arm **134a**, or to a spring mechanism (not shown). The mechanical cycle of the mechanism **120** may then begin again.

Fig. 12 shows a pump **1200** in accordance with another embodiment of the invention that executes the temporo-spatial array of valve activation shown in Fig. 4, to generate flow in an elastic tube **1205**. The pump **1200** is shown in a front view in Fig. 12a, and in a rear view in Fig. 12b. In the pump **1200**, a segmental actuator **1010a** is rotatable around a pivot **1015a**. The segmental actuator **1010a** has a first notch **1020a** and a second notch **1025a**. The first notch **1020a** and the second notch **1025a** are separated by an inter-notch region **1022a**. The position of the segmental actuator **1010a** is determined by a pair of electromagnets **1005a** and **1006a**. When the electromagnet **1005a** is activated, the segmental actuator **1010a** rotates counter clockwise (when viewed from the perspective of Fig. 12a) so as to bring the first notch **1020a** between a first end **1031a** and a second end **1032a** of a metal core **1033a**. The segmental actuator thus assumes a first position shown in Fig. 12. When the electromagnet **1006a** is activated, segmental actuator **1010a** rotates clockwise (when viewed from the perspective of Fig. 12a) so as to assume a second position (not shown) in which the second notch **1025a** is between a first end **1036a** and a second end **1037a** of a metal core **1038a**.

A lever **1045a** has a first valve head **1055a** and a second valve head **1056a**. The lever **1045a** is fixed to the segmental actuator **1010a** and rotates about the pivot **1015a** from a first position in which the valve head **1055a** is lower than the valve head **1056a**, as shown in Fig. 12, and a second position in which the valve head **1055a** is higher than the valve head **1056a** (not shown). The lever **1045a** is fixed to segmental actuator **1010a**, so that the position of the lever **1045a** is determined by the position of the segmental actuator **1010a**. When the segmental actuator **1010a** is in its first or second position, the lever **1045a** is also in its first or second position, respectively. A permanent magnet **1040a**, attached to the base **1041** of the pump, latches the lever **1045a** and the segmental actuator **1010a** in their first position. A

- 14 -

permanent magnet **1042a**, attached to the base **1041** of the pump, latches the lever **1045a** and the segmental actuator **1010a** in their second position.

A second segmental actuator **1010b** is rotatable around a pivot **1015b**. The segmental actuator **1010b** has a first notch **1020b** and a second notch **1025b**. The first notch **1020b** and the second notch **1025b** are separated by an inter-notch region **1022b**. The position of the segmental actuator **1010b** is determined by a pair of electromagnets **1005b** and **1006b**. When the electromagnet **1005b** is activated, the segmental actuator **1010b** rotates clockwise (when viewed from the perspective of Fig. 12a) so as to bring the first notch **1020b** between a first end **1031b** and a second end **1032b** of a metal core **1033b**. The segmental actuator thus assumes a first position shown in Fig. 12.. When the electromagnet **1006b** is activated, segmental actuator **1010b** rotates counterclockwise (when viewed from the perspective of Fig. 12a) so as to assume a second position (not shown) in which the second notch **1025b** is between a first end **1036b** and a second end **1037b** of a metal core **1038b**.

A lever **1045b** has a first valve head **1055b** and a second valve head **1056b**. The lever **1045b** is fixed to the segmental actuator **1010b** and rotates about the pivot **1015b** from a first position in which the valve head **1055b** is lower than the valve head **1056b** (not shown), and a second position in which the valve head **1055b** is higher than the valve head **1056b**, as shown in Fig. 12. The lever **1045b** is fixed to **1010b**, so that the position of the lever **1045b** is determined by the position of the segmental actuator **1010b**. When the segmental actuator **1010b** is in its first or second position, the lever **1045b** is also in its first or second position, respectively. A permanent magnet **1040b**, attached to the base **1041** of the pump, latches the lever **1045b** and the segmental actuator **1010b** in their first position. A permanent magnet **1042b**, attached to the base **1041** of the pump, latches the lever **1045b** and the segmental actuator **1010b** in their second position.

The temporo-spatial array of activation of the four electromagnets **1005a**, **1006a**, **1005b**, and **1006b**, is determined by a driver (not shown) so as to activate a predetermined temporo-spatial array of valve head positions. Valve heads **1055a**,

- 15 -

and **1056a** are never open or closed simultaneously. The same also applies to **1055b** and **1056b**. This is consistent with the temporo-spatial array of valve head activation shown in Fig. 4.

Two or more pumps of the invention may be used simultaneously in a  
5 pumping system. For example, two pumps may be positioned in series along a conduit, or may be positioned in parallel along two branches or tributaries of a conduit.

The pump of the invention may further comprise an anti-free-flow device **1047** (see Figs. 12a and 12b). The anti-free flow device prevents flow of liquid in  
10 the tube when the tube is being inserted or removed from the pump.

Fig. 15 shows an anti-free flow device **1500** that may be used with any of the pumps of the invention. The anti-free flow device **1500** includes a sleeve **1505** that contains a portion of a tube **1520**. Lever **1510** is spring biased by a spring **1515** so as to press upon the tube **1520** so as to occlude the lumen of the tube **1520** when  
15 the device **1500** is not inside the pump. When the sleeve is in position inside the pump, and the pump door is closed, a pin located on the inside surface of the door depresses the lever **1510** away from its spring biased position so as to open the lumen of the tube **1520** and allow flow of liquid in the tube.

Fig. 16 shows another anti-free flow device **1600** that may be used with the  
20 pump of the invention. The anti-free flow device **1600** has a "C" shaped body **1610**. The ends **1615** and **1620** are spring biased by a spring **1625** to press upon a tube **1630** so as to occlude the lumen of the tube **1630** when the device **1600** is not located inside the pump. When the device is inserted into the pump, the end **1615** of the body **1625** engages a member fixed in the pump having a slanted surface so  
25 as to urge it up from its spring biased position, so as to open the lumen of the tube **1630** and allow flow of liquid in the tube. The end **1615** has a slanted surface **1635**.

In a preferred embodiment, the pump of the invention is powered by one or more batteries, so that the pump is portable as shown in Figs. 13 and 14. As shown in Fig. 13, a portable pump **1300** of the invention **1300** may be received in a padded  
30 pouch **1305** that protects the pump **1300** from mechanical shocks during use. The

- 16 -

pouch **1305** is provided with straps or clips **1310** in order to affix the pouch and pump onto a user's body or clothing. The pouch includes a container **1307** for a fluid that is to be pumped by the pump and infused into the user's body. The pump **1300** has a control panel **1325**. The pump **1300** has a control panel **1325**. The

5 control panel **1325** has a display screen **1330** that displays various parameters of the pumps functioning (for example, the pumping rate, the total volume that has been pumped, the time that the pump has been in operation, or the occurrence of a malfunction in the pump) The control panel **1325** also has input buttons **1335** for selection of pump parameters, such as the pumping rate. The control panel **1325**

10 may be detachable from the rest of the pump **1340**, as shown in Fig. 14, in order to facilitate viewing of the display screen or input of pump parameters. The control panel **1325** may communicate with the rest of the pump **1340** by a cable **1345** that is retractable inside the pump and out of view when the control panel **1325** is attached to the rest of the pump **1340**, as shown in Fig. 13. Alternatively, the control

15 panel **1325** may communicate with the unit **1340** of the pump by a wireless connection (not shown). The pump **1300** may also be equipped with a transceiver **1315** communicating with a remote transceiver **1320**. The transceiver **1315** may transmit to the remote transceiver **1320** information relating to operation of the pump such as the pumping rate, the total volume that has been pumped, the time

20 that the pump has been in operation, or the occurrence of a malfunction in the pump. The remote transceiver **1320** may be used to program the pump in stead of the control panel **1325**.